Assess the impacts of human mobility change on COVID-19 using differential equations with Google Community Mobility Data

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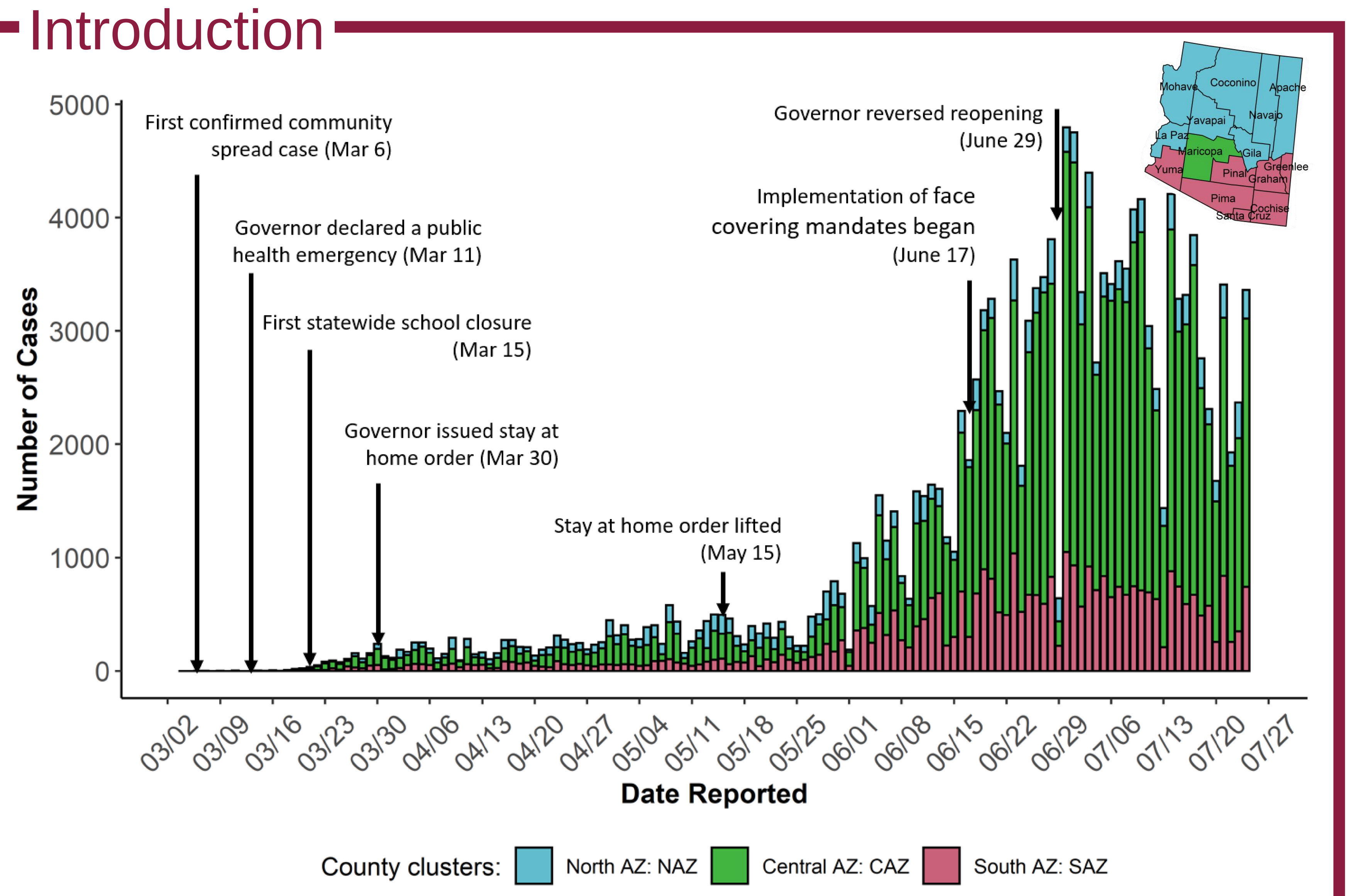
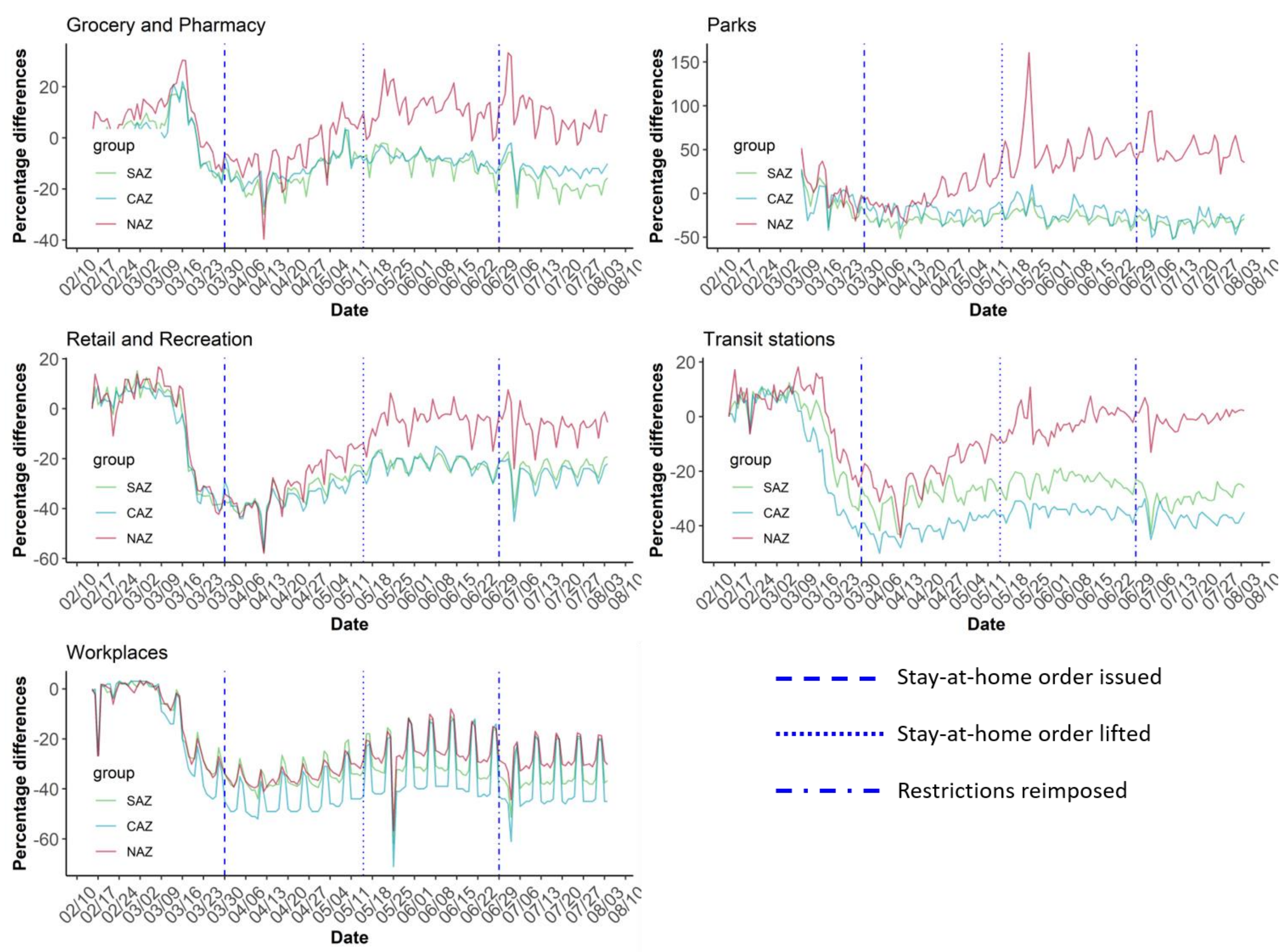
Introduction



- In June 2020, Arizona, U.S., emerged as one of the world's worst coronavirus disease 2019 (COVID-19) spots after stay-at-home order lifted.
- Mobility restriction is one of the few interventions that is known to be effective in mitigating the disease spread.
- Government decided to reimpose coronavirus restrictions and that appeared to have paid off.

Data sources

- Incorporated the Google Community Mobility Reports to model the inter-region human movement
- The reports provide the changes in movement trends compared to baselines overtime across five different categories of activities:



PDE model

Let $C(x,t)$ represent the COVID-19 cases in Arizona region x at a given time t

$$\frac{\partial C(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(d(x)\frac{\partial C(x,t)}{\partial x}\right) + r(t)l(x)a(x,t-14)C(x,t) - c\frac{h(x,t-14)C(x,t)}{k + C(x,t)}$$

$$C(x,1) = \psi(x), 1 < x < 3$$

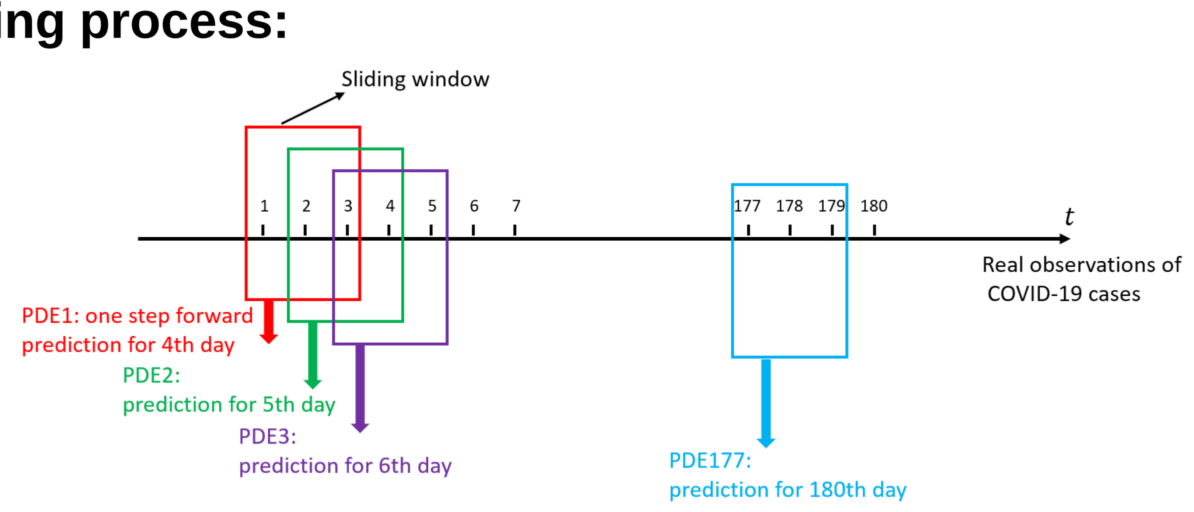
$$\frac{\partial C}{\partial x}(1,t) = \frac{\partial C}{\partial x}(3,t) = 0, t > 1$$

The spread of COVID-19 cases between different Arizona regions.

The COVID-19 cases in a local Arizona region at location x and time t.

The rate of COVID-19 case decrease due to human efforts.

Forecasting process:



ODE model

For a given region i, the evolution of the population in each status over time can be described by

$$\frac{dS_i}{dt} = -\left(\sum_{j=1}^{3} \beta_j \frac{I_j}{N_j} p_{ij}\phi_j(t)\right) S_i$$

$$\frac{dI_i}{dt} = \left(\sum_{j=1}^{3} \beta_j \frac{I_j}{N_j} p_{ij}\phi_j(t)\right) S_i - \gamma_i \widehat{\phi_i(t)} I_i$$

$$\frac{dR_i}{dt} = \gamma_i \widehat{\phi_i(t)} I_i$$

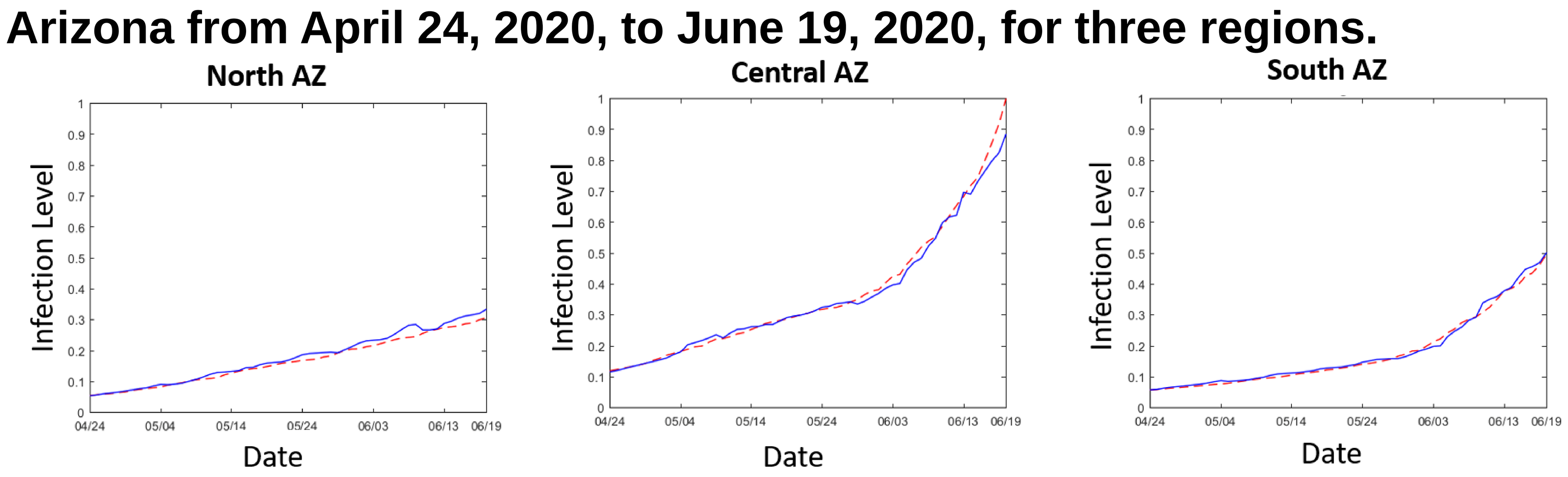
where β_i is the transmission rate, γ_i is the recovery rate, p_{ij} describe the intra-region relative contact rate between region i and region j (i.e. $p_{ij} = 1$ for $i = j$). $\phi_i(t)$ is a function which describes activities outside of the home and $\widehat{\phi_i(t)}$ describes stay-at-home activities and it is written in a form

$$\phi_i(t) = \begin{cases} \frac{1}{1+\exp(-m_i(t-10))}, & i = j \\ 1, & otherwise \end{cases}$$

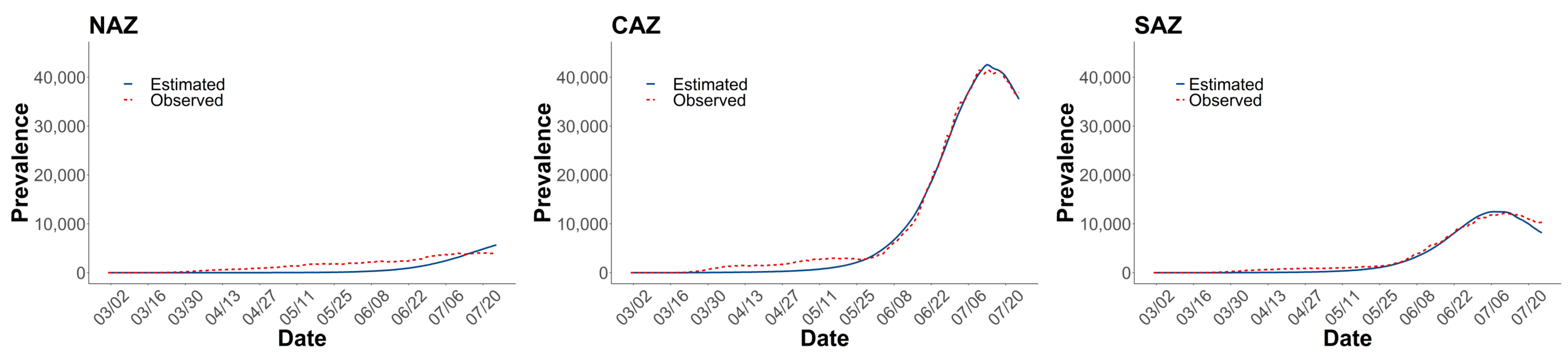
where $m_i(t-10)$ is empirical data for human mobility.

Results

【PDE model】Predictions of cumulative number of COVID-19 cases in Arizona from April 24, 2020, to June 19, 2020, for three regions.

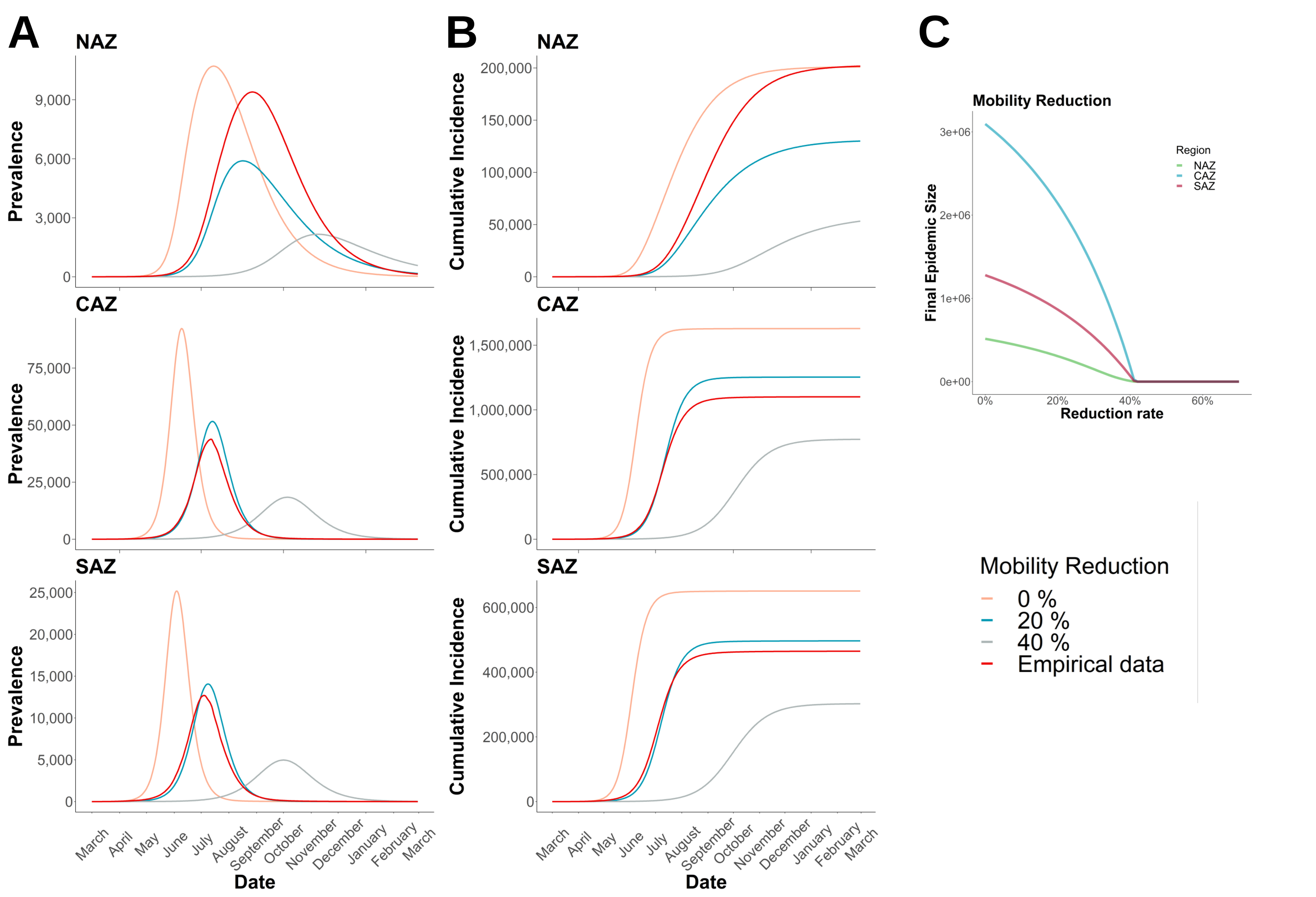


【ODE model】Predictions of prevalence of COVID-19 cases in Arizona from March 1, 2020, to July 25, 2020, for three regions.



Effects of human mobility in Arizona on COVID-19 cases

(A) Daily prevalence of COVID-19, (B) Cumulative incidence of COVID-19 with mobility restrictions varied 0%, 20% and 40%, and empirical data.
(C) Final epidemic size with varying mobility reductions from 0% to 70%.



Conclusion

We have presented both PDE and ODE model to predict COVID-19 epidemic. While the situation around COVID-19 in Arizona has been improving, the epidemic is not yet under control, and a large proportion of the population is still susceptible. As the trajectory of the outbreak in Arizona and beyond will depend on human mobility, implementing rapid and effective control measures are advised based on the experiences in Arizona.